VIRTUAL REALITY AND SIMULATION

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ABSTRACT

Virtual Reality is a leading edge technology which has only very recently become available on platforms and at prices accessible to the majority of simulation engineers. The media representation of Virtual Reality has been focused on the entertainment aspects of the technology. As a result many simulation engineers are unaware of or confused by the concepts embodied in applying Virtual Reality to simulations.

The objective of this state-of-the-art review is to provide an awareness of Virtual Reality with respect to simulation.

A brief tutorial will be presented to clarify the terminology employed in the field. Examples of applications in a range of fields will be given, using Virtual Reality software combined with a variety of simulation engines. Virtual Reality devices will be available affording attendees to experience different modes of involvement with the simulated environment.

1.0 INTRODUCTION

Virtual Reality (VR) is a leading edge technology that has only recently become available to simulation professionals. The newer workstations and PCs provide performance that supports VR at an affordable price. VR software is now available to run on these platforms. Perhaps most important for this audience, some of this software comes with simulation engines that support simulation modelling and analysis.

The evolution of modern simulation modelling tools has encompassed prototypes, physical models, programming languages, simulation languages, animations of simulation results and visual interactive simulations. At each step in this progress there was confusion and misunderstanding concerning both the new technology and its value to the simulation process. The purpose of this paper is to describe the tools and methods that are particular to VR and to illustrate how these are being applied to simulation.

2.0 WHAT IS VIRTUAL REALITY

VR is the term used to describe advanced methods of involvement and interaction for humans with a computer-generated graphical (usually 3D) environment. Normally referred to as a VR "world," this environment is experienced by a human participant through the use of special VR equipment. In simulation terms, VR can be thought of as an advanced user interface to 3D simulation models.

VR equipment provides the human with sensory information about the VR world. This can include 3D viewing, sound, touch and smell which have all been employed to stimulate the senses so as to increase the illusion that the human is a participant in this VR world. The objective of the technology is to obtain a level of human involvement (sometimes referred to as immersion) with the VR world that is suitable to the task at hand. Different tasks require different levels of involvement. For example, airplane flight crisis simulator VR worlds are most effective when they persuade the human to generate an emotional involvement with the situation. Scientific VR worlds designed to promote insight and analysis do not usually require this level of emotional involvement.

As important as reception of information by the human senses is, it becomes much more valuable when the human can interact with the VR world. VR equipment allows the human to change position and orientation in the VR world. This is the equivalent to "moving" through the VR world. There is also the capability to interact with the VR world, obtaining information and making instantaneous changes to the VR world.

3.0 VR IN THE MEDIA

The popular media representation of VR has tended to emphasize the entertainment aspects of the technology. The depiction of VR use by characters in science fiction movies and television programs has a limited impact. This is because the real world viewer is watching a 2D animation of actors who are supposed to be experiencing

VR. There is no VR experience for the real world viewer, no 3D viewing and no interaction. In an effort to overcome this perception gap, graphics special effects are often used to ensure a high impact on the real world viewer. For example 'morphing' and graphics panning, zooming and flying around graphics provide impressive special effects. This representation has promoted an awareness about VR but has caused some confusion about what VR technology is. Whilst these graphical tricks can be applied within VR they do not by themselves constitute VR.

True VR can be experienced with some computer games. These VR games allow one or more participants using VR equipment to be able to see and "move" within a 3D VR world. The human(s) can also perform specific actions in this VR world. In this type of game, the human is truly involved and interacting with a VR world. These games have tended to be fairly simple so far, however they have a high impact on participants because they utilize all the essential elements of VR.

Much of the technical literature has concentrated on the capability to move around a VR world that is unchanging or "static." A "walk through" of a planned building or around a conceptual automobile or airplane is an excellent communication exercise. It can even provide problem identification and resolution capabilities. These VR worlds are an extension of the 3D CAD tools that allow for the creation of a 3D representation, or model, of some static object or objects. In these examples the VR aspect is mainly the manner in which the human views the model. In more advanced VR worlds of this static type, the human can interact with the VR world. For example, lifting the hood on a car or selecting a change of color for the car body.

4.0 VR AND ANIMATION

Animation of some or all of the objects in the VR world provides the human with an experience that can seem quite realistic. Because humans have an acute awareness of time passing, animation which represents change through time increases the human sense of involvement dramatically. Many VR worlds are based purely on fixed animations and therefore human interaction is limited to changing such factors as position and orientation of view. This is particularly so when the VR world is simply replaying a 3D animation, without any underlying simulation engine. When the human can interact with a VR world that is being animated, there is a strong sense of involvement and participation. Where the level of interaction enables changes to be made to the VR world that are immediately reflected in the behavior of the animated VR world, human interactions are closely parallel to human interactions with the real world.

5.0 VR AND THE REAL WORLD

In this paper VR worlds will be described that are closely related to existing or proposed real environments. These VR worlds provide animation that is based on rules of behavior and data in the model. In these worlds, the human can interact to change rules or data and the animation will change accordingly. As a result, these VR worlds provide human participant(s) with experiences and feedback data that enable valid and valuable inferences to be made about the real environments.

6.0 VR AND SIMULATION

If this sounds familiar to an audience of simulation professionals, this is to be expected. Similar terms could be used to describe simulation models. However, there are aspects of VR that differentiate it from simulation tools to date. These aspects include the manner in which the human experiences the simulation model, the degree to which the experience appears true to life and the manner in which the human can interact with the model. To reiterate an opening remark, VR in simulation can be regarded as an advanced user interface to a 3D simulation model.

7.0 VR EQUIPMENT

In the context of this paper, the order of importance for VR devices is sight, view control, and interaction (including touch). In order to place these in perspective, a description is given of the status of devices for sound, smell, taste and even (yes really!) mind control.

7.1 Sight

The most common VR equipment handles how the human sees the VR world. The stereo glasses employed by 3D movies are a commonly understood example of this type of equipment. Put simply, two coordinated and simultaneous images are produced and each image is directed to a separate eye. In this way the human viewer sees a 3D image.

A computer monitor can produce the two images, which can then be interpreted by a set of special VR glasses that will show a 3D view to the human. In a similar way, higher quality devices can be used. For example, head sets and other VR devices employ liquid crystal displays to provide each high quality image.

7.2 View Control and Tracking

The control of the human's view of the VR world is an important interactive capability of VR. The use of key-

board and mouse becomes difficult quickly when the human cannot see the devices. Hand held devices such as a remote mouse allows much better interactive view control. This works well with glasses or head-mounted devices.

A Binocular Omni-Orientation Monitor (BOOM) allows the user to move the viewing device itself with periscope-like movements. The computer registers the movements and changes the view position and orientation accordingly. There are now desk top devices that combine 3D viewing and view control features.

The most attractive view control VR device may well be a tracker. A tracker allows the computer to monitor the position of the human and to alter the VR world view according to the human's movements. There are a variety of tracker devices.

The ability of the VR world to react quickly to a view control command is very important to the human's sense of the realism of the VR world. If the VR world view change is too slow to react, it is difficult for the human to maintain involvement. As an example, if you turn your head in the real world you will instantly see a new view. That is because the real world is "on display" constantly. However, in the VR world a fast turn of the head may get ahead of the computer's ability to generate the new views and a "lag" effect will be experienced. This is a significant issue in the design and selection of VR equipment and software.

7.3 Interaction

Tracker devices by their nature provide input to the computer on the location of the tracker device. It is a natural extension to link similar devices to the VR world as interactive input devices that do more than register location. A glove that contains flexible fiber optic cabling and 20 or more sensors can be used to register complex combinations of locational information in the VR world. One use of such devices is to monitor complex manual activity as input to control equivalent manual operations in the VR world. An extension of this would be to provide complex commands to the VR world such as by the medium of International Sign Language. Another extension would be to provide interactions with the VR world such as grabbing or manipulating VR objects.

Tracker technology extends to full body suits which can be used to control an animated figure within a VR world.

7.4 Voice Control

Voice control is now available on standard PCs. However, the quality of general tools for this type of interactive control is not at a point that its application to any VR world is simple and cheap.

7.5 Miscellaneous Devices

Laser pointer devices that display within the VR world provide the equivalent of point and click control on a screen.

In summary, there are many alternative interactive control mechanisms. The choice is likely to depend on the application.

7.6 Touch

With the use of a set of trackers, the various parts of the human's extremities can be tracked. In this way, the human extremities can be tracked to see if they are in contact with some object in the VR world.

This mechanism can be enhanced by the use of force feedback, which exerts pressure on the human body to simulate touching an object. Simulating the texture of touch is beyond current technology.

7.7 Sound

Humans are by now very used to the various methods of sound reproduction. Most typically with a computer device, digital sound recordings can be replayed and fed to the user through speakers or headphones. Stereo or even surround sound is already established technology. The integration of tracker devices with the sound reproduction mechanism will allow the human to experience omnidirectional and distance-based sounds. This technology has a clear attraction outside the VR world.

7.8 Smell

The application of smell in VR is still at the level of basic research.

Over 30 different basic smells have been identified. By employing combinations of these, a wide range of aromas can be generated. Omnidirectional and distance-based smell production requires some development but there is a reasonably clear path towards it.

7.9 Taste

This technology is further away than smell. Artificial flavors provide some capability. However the application of this to Virtual Reality is at the research level now. Problems of the association between taste, texture and smell are complex problems which have yet to be tackled for Virtual Reality applications.

7.10 Biocontrol

This technology exists only as research projects. Eye movements and muscle movements can be monitored and used to interact with the VR world. As with several other aspects of VR, the technology has applications outside of VR. For example, eye movement has been used in camcorders to assist the focusing mechanism.

Successful experiments have even been performed where the subject was able to learn to control their own brain waves by using EEG brain wave monitoring device feedback. The EEG devices were then hooked up to a computer and control rules established so that certain brain wave combinations would be interpreted as commands to the computer. In this way subjects were able to mentally manipulate a cursor.

8.0 AREAS OF SIGNIFICANT INTEREST

8.1 Shared VR worlds

VR worlds can be shared by more than one human at a time and, through networks, humans in different physical locations can participate simultaneously in a single VR world. Bandwidth limitations make this difficult to implement, however there are some applications of this that are commercially available.

8.2 VR for remote control

The control of remote robotics devices by an operator in a VR world is available. One application of this is for hazardous environments.

9.0 APPLICATIONS

In the applications described below, VR worlds have been created that are 3D and that realistically represent existing or planned environments. The VR world is animated with behavior controlled by a simulation engine which uses simulated behavior rules and model data.

9.1 Primary Elements of Virtual Manufacturing

Visualization allows the user to assemble the components in a Virtual Manufacturing cell. This could be by utilizing the 3D models of the part designs using popular CAD packages, such as Unigraphics, Intergraph, CATIA or Pro/ENGINEER to visualize how the components relate to each other. Sikorsky used Deneb's IGRIP simulation software to recreate the actual manufacturing process. In the model, the user can manipulate and view each of the components to develop a manufacturing approach (reference Figure 1).
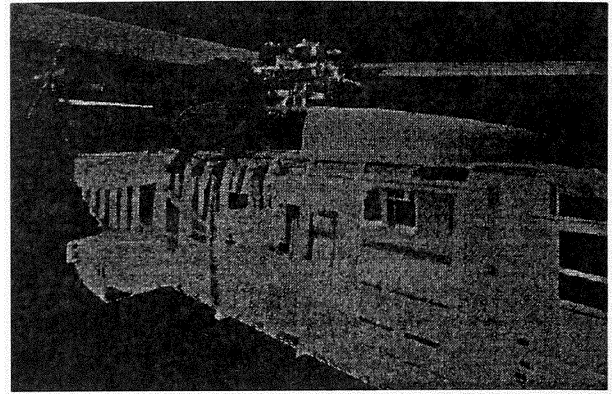
Figure 1. 3D Visualization

Virtual Manufacturing modelling allows the user to introduce the engineering design to the processes that will be used to create the actual part, assembly, or installation. The tool design is imported to the model, combined with the part and dynamic representations of the machines that will produce the part. Machines such as 5-axis milling centers or processes such as aircraft joining are programmed to operate identically in the virtual environment as they would in the real environment. Design problems such as collisions, clearances, missing manufacturing features, fit, and manufacturing sequence issues are quickly identified. Manufacturing and design concepts are easily developed with minimal cost to the program. The ability to insert people in the environment and analyze their activities minimizes ergonomic problems.
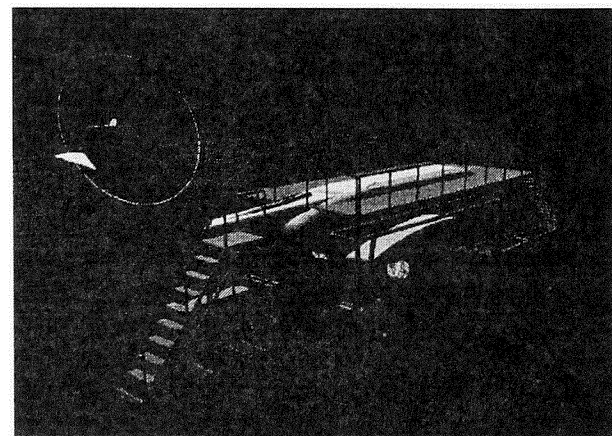
Figure 2. Workcell Modelling

Factory modelling allows engineers to predict the cost and schedule impact of potential design or process

changes. The discrete process modelling tool, QUEST, is used by Sikorsky to model the impact of machine run times, set up times, resource constraints, part lot quantity, and many other factors to develop a simulation that mirrors the entire manufacturing process under review. The information provided by the simulation enables "what if" analysis. The model provides support personnel with a tool to optimize the manufacturing process, try new concepts without disrupting manufacturing and predict changes due to load variations. Figure 3 is an example of a model of a sheet metal manufacturing center. The graphical interface allows the manufacturing experts to actively participate in validating the model.
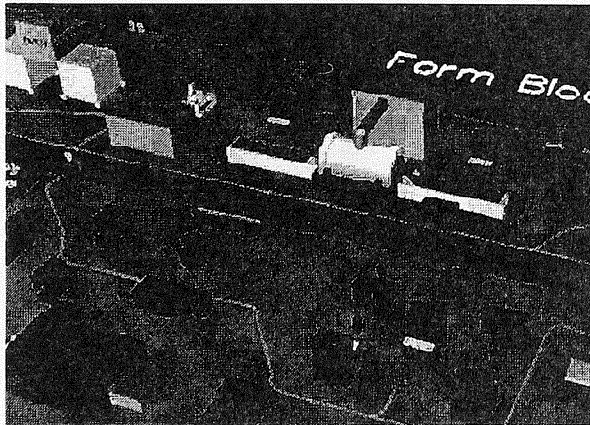

Figure 3. Discrete Process Modelling

Virtual Manufacturing has enabled Sikorsky manufacturing personnel to directly influence the design process. They improved transfer of data between partners and suppliers, allowed for in-depth product visualization and enabled advanced graphic database management — all in an effort to rapidly respond to customer demands.

The three common elements in the evolution of a product are cost, schedule, and information. Virtual Manufacturing allows engineers, designers, suppliers, and others to understand the cost and schedule impact of decisions and to consolidate processes.

Overhead costs are addressed by improving schedule performance. The amount of time it takes to design, plan, tool and manufacture a product directly impacts overhead costs. As illustrated in Figure 4, a reduction in the time it takes to get a product to market equates to a return on investment (ROI) improvement.
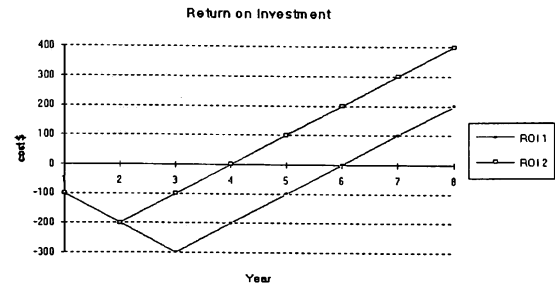

Figure 4. Courtesy of Sikorsky Aircraft

9.1.1 Scenario

The following discussion represents a typical manufacturing and design scenario at Sikorsky where they have integrated Virtual Manufacturing into their IPPD process.

In Phase 1, they derive a sound manufacturing concept to optimize cost, schedule, and account for all design issues such as weight and stress. This is the original conceptualization phase where the IPPD team determines the cost and schedule impact of decisions.

In Phase 2, they validate the manufacturing and design plan by simulating the actual manufacturing processes and equipment that are used either in-house, at suppliers, or at partners, to ensure that the design intent is being met. At this time, the IPPD team predicts the tolerance the process can yield and validates the manufacturing processes (reference Figure 5).
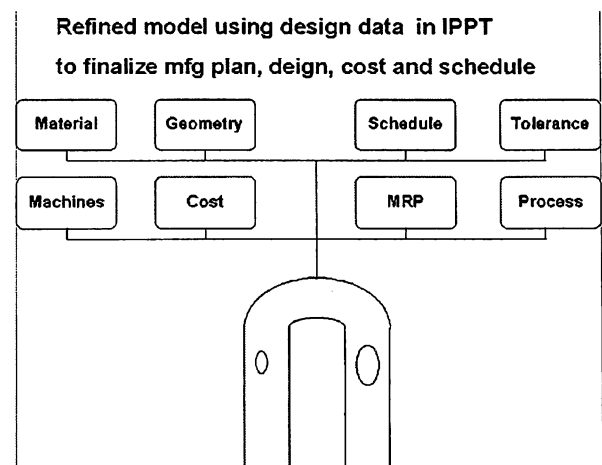

Figure 5. Manufacturing Validation

In the Phase 3, they use Virtual Manufacturing to

manage internally and externally generated changes by predicting what effects the changes will have. Results provide instant access to cost and schedule impact and provide visibility as to manufacturing capability.

9.1.2 Conclusion

At Sikorsky Aircraft, the ability to remain competitive will be closely tied to reducing lead times, improving schedules, and eliminating unwarranted costs. Virtual Manufacturing will be one of the key enabling technologies used to realize these goals by bringing all the decision drivers up front, dramatically reducing the overhead costs commonly associated with product/process development activities.

9.2 Airfoil Manufacturing Cell

British Aerospace, United Kingdom, is using QUEST, Virtual NC®, and evaluating IGRIP and Deneb/ERGO™ to conduct a number of aircraft manufacturing studies.

The site is familiar with the use of simulation and already have a capability. They are however, particularly interested in the use of QUEST for high value new start projects, where the superior visualization is a valuable tool within their concurrent engineering environment. It also provides a good insight to the maturity of facility definition for their customers.

One QUEST-based model was created to determine how increased build rates, spare parts, and repairs would impact production. The issues they wished to investigate included facility sizing, shared facility analysis, floor space management, and estimation of tooling requirements.

To create the QUEST model, legacy CAD data of the production facility was imported from CATIA, Intergraph, AutoCAD and ANVIL CAD systems. This highlighted an additional benefit of allowing CAD data from multiple courses to be viewed on a single screen. BAe modelled proposed facility enhancements to accommodate increased production whilst maintaining a robust and flexible manufacturing facility. The impact of enhancements are difficult to visualize in 2D simulators. Issues for BAe included space and labor allocation, material flow, bottlenecks, throughput, and accurate modelling of manufacturing cells.

The machining and treatments facility at BAe, Samlesbury is using Virtual NC for detailed process analysis. They have modelled 4 and 5 axis milling machines tooling and jigs to prove-out a large percentage of complex part programs before beginning actual machining. This particular approach has contributed to a reduction in part program prove out time on line machines.

One particular problem BAe had experienced in the past was "shanking." Shanking is largely due to a product/tooling design flaw, and occurs when the shank of the tool collides with the workpiece or its fixture. Virtual NC's near-miss and collision detection facilities allowed BAe to prove-out the complex NC programs and eliminates all such collisions.

Today, Virtual NC is also being used to evaluate new machine tools, fixtures and jigs, verifying the reachability of a component to the machine and programs before implementation in the production facility.
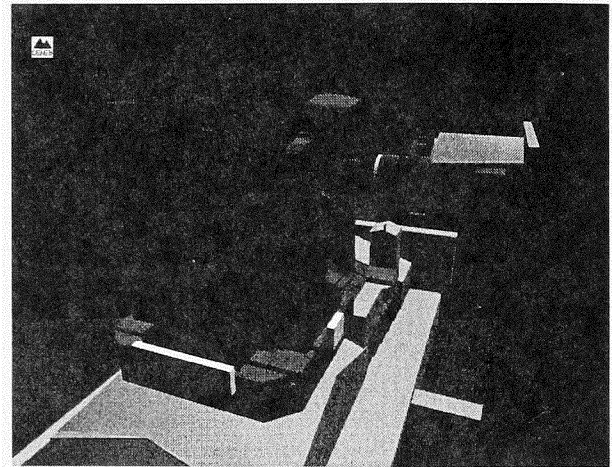

Figure 6. Courtesy of British Aerospace

The benefits from Virtual Manufacturing the BAe engineers realized include:

- Integration of the CAD systems allow data from multiple sources to be viewed on a single screen. These floor layouts can be populated with tooling geometry. This allows fast reviews to be carried out, and checks to be made on whether the tooling fits within the layout as expected and if there is any interference between buildings, tooling, and piece parts.
- The ability to replay existing Virtual NC, Deneb/ERGO, IGRIP, and QUEST models means there is no overhead in reusing existing data.
- 3D simulation allows better communication of ideas/concepts to both management and shop floor operators.
- More accurate modelling of material handling systems making it simpler to view the progress of production through the facility.
- Checking NC programs for collisions and workpiece damage prior to production. This reduces downtime, scrap, and tape prove-out time on the machine.

9.3 Sacramento Air Logistics Command

When stringent air regulation amendments to the 1990 Clean Air Act threatened U.S. foundries with significant capital costs for retrofitting or forced closure, the government and private sector formed the Casting Emission Reduction Program (CERP) to address the environmental issues. QUEST interactive 3D graphics discrete event simulation software supported the CERP project team at U.S. Air Force Advanced Manufacturing Center of the Sacramento Air Logistic Command at McClellan Air Force Base, Sacramento, CA, to demonstrate the viability of a pilot foundry prior to construction. The foundry will be built at McClellan AFB in 1996 to conduct environmental and process experimentation.

CERP participants include McClellan Air Force Base, SALC, and the Environmental Research Consortium, a committee of the U.S. Council for Automotive Research (USCAR) which is a U.S. auto company coalition. The consortium includes Chrysler Corp., Ford Motor Co., GM, and Navistar International. The Environmental Protection Agency (EPA), the California Air Resources Board, and the American Foundrymen's Society are also participants.

Over 90 percent of all manufactured items used by the DoD either are castings, contain castings, or are derived from castings. The weapon systems used by the military make large scale use of metal castings. Castings are also critical in the private sector. Automobiles and transportation equipment use 50 to 60 percent of all castings produced.

To revitalize the U.S. foundry industry, CERP's initial goal is to develop new materials, processes or equipment for metal casting manufacturing that will achieve a near-zero effect on the environment.

CERP's objectives included building a pilot facility for testing and research, collecting data on actual emissions, developing low level emission testing equipment, and modelling foundry processes.

QUEST and IGRIP were used by SALC manufacturing engineers to develop the foundry simulation model.

The initial model was conceptual. Even so, the content, like the object library that was created, could be used to prepare the technical model. During design review, this initial model served as a baseline from which to conduct analyses to optimize the layout. Very specific data from the design group was incorporated — feeds, flows, and equipment.
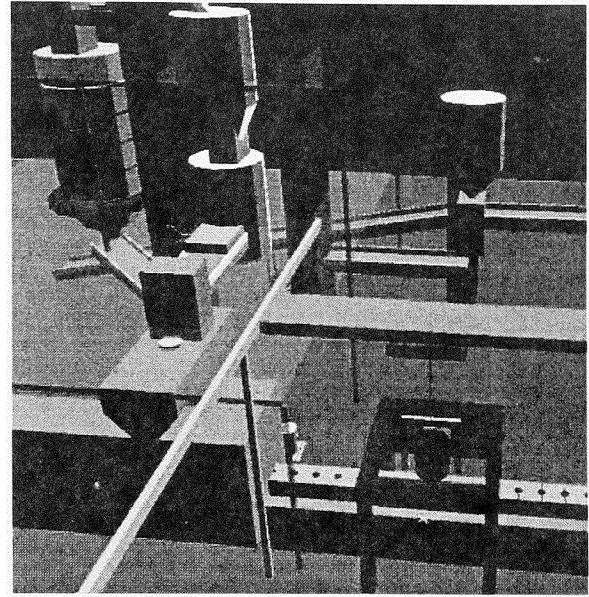
Figure 7. The Virtual Prototype of the Proposed Foundry

Eventually, the software will be used for time and motion studies, and to analyze human factors and do time study measurement in lieu of doing engineered time standards.

As the simulation matured and was shown to molders who actually work in the foundry, their input on how specific setups would work were added to the database. The simulation also became a valuable tool for training employees.

Using virtual reality technology, the government and private sector CERP team has demonstrated the usefulness of virtual reality modelling in design. QUEST is helping in the design of a flexible and relevant pilot foundry that will help the industry find new, low environmental impact ways of doing business. The simulations have proven to be a valuable design tool, as well as a communication and visualization tool to help make the project "come to life" prior to construction.

## 9.4 Other DoD Applications: Next Generation Submarine being Developed with Virtual Technologies

Prototypes of a nuclear attack submarine being developed by General Dynamics Electric Boat Division for the Navy are being designed, evaluated, and optimized in a virtual environment. Operating under a contract from the Advanced Research Project Agency's (ARPA)

Marine Systems Division, Electric Boat demonstrated the feasibility of state-of-the-art simulation-based design (SBD). The objective was to implement an accurate, efficient, and dynamic environment for design, rapid prototyping, concurrent product and process development, mission planning, operation maintenance, and training. Traditional prototyping methods can take several months to physically build and test, and at a great expense. Subsequent to the ARPA demonstration, Electric Boat has adapted the SBD approach to design and now utilizes 21 seats of ENVISION software.

By simulating the kinematic, dynamic, mechanical, and other characteristics of the submarine, its components and subsystems, engineers can create a multi-disciplinary environment in which to evaluate a wide range of parameters and optimize the design based on the results.

The first phase of the SBD project was to demonstrate the feasibility of designing and evaluating the next generation submarine in a virtual environment. Electric Boat selected ENVISION to visualize design concepts and integrate components and subsystems. Electric Boat also uses ENVISION to visualize the results of the model's maneuverability tests in a virtual undersea environment. From the data provided by an external hydrodynamic analysis program being visualized (Figure 8) in the simulation, engineers can optimize the conceptual designs, including consideration of both the submarine's performance characteristics and the cost ramifications of a proposed design change.
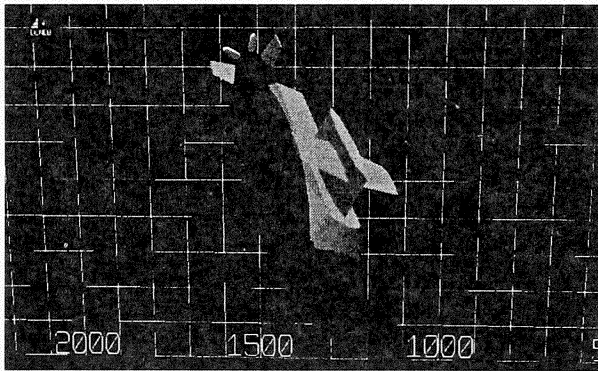

Figure 8. ENVISION's 3D graphics allow engineers to evaluate the impact of design modification by conducting maneuverability tests in a virtual, undersea environment

In a proof of concept demonstration to the ARPA, Electric Boat featured its SBD capabilities and concurrent engineering methods enabled by the virtual technologies. Developmental submarine models were created by importing CAD data from Parametric Technology,

Computervision, CATIA, and Intergraph software packages. The submarine hull was simulated operating at various speeds and directions in a "virtual sea" to evaluate its performance. Using Pro/ENGINEER CAD software, the hull design was modified, re-imported into ENVISION, and simulated again. The comparison simulations enabled the engineers to evaluate the impact of the design modifications on maneuverability. Because of the seamless migration from CAD systems to ENVISION, Electric Boat engineers were able to generate and simulate each design iteration in about 10 minutes.

The driving force behind Electric Boat's pioneering work with virtual technologies is the critical need to reduce the time and cost required for designing, engineering, and building a submarine. The development window has been as long as 14 years for previous submarines. Electric Boat feels they can reduce this time to six or seven years with virtual technologies.

Virtual engineering allows the parties involved with design, manufacturing, operations, and maintenance to jointly contribute to the design process early in the cycle. Electric Boat engineers often experience communication difficulties when trying to describe innovative ideas to people not trained in their particular discipline. The physically accurate 3D models simulated in ENVISION help engineers and technicians from various disciplines to comprehend new ideas and concepts. In addition, virtual reality technologies such as immersion enable engineers and their naval customers to "walkthrough" the model with visual feedback. Immersion provides for evaluation of other design criteria, such as ergonomics, before a design is built.
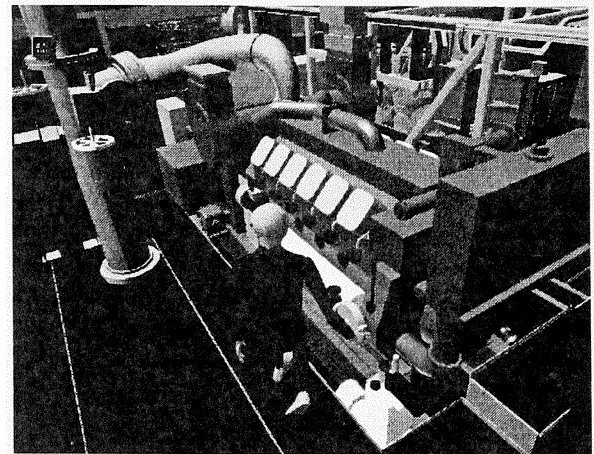
Figure 9.

Deneb, IBM Federal Systems (acquired by Loral Corp.), Intergraph, the University of Iowa, Silicon Graphics, and Parametric Technologies are working with Elec-

tric Boat to prove out SBD concepts and the applicability of virtual technologies to engineering.

Already the benefits of applying virtual technologies to engineering, manufacturing, mission planning, operations, maintenance, and training are evident. At Electric Boat, the ability to optimize systems through concurrent engineering, lowered costs and reduced times to product delivery are just a few of the more significant benefits of SBD and virtual engineering. The virtual engineering systems that evolve from this project will be applicable to most complex product design endeavors with similar benefits. Electric Boat has adopted the SBD paradigm and the ENVISION software as key elements of the design process.

9.5 Virtual Collaborative Engineering

The most recent development in the use of Virtual Manufacturing software is the use of the Virtual Collaborative Engineering (VCE) environment that links multiple users at multiple locations to discuss, analyze, and review simulations over a wide area network. VCE users interactively evaluate design concepts, manufacturing tooling, processes, and factory layouts — even at geographically remote locations. Any VCE user can assume control of a simulation, make changes, or view changes made by others on the VCE network. Engineers, manufacturing personnel, system operators, or other users interact within the same simulation, creating a "virtual conference room" for design discussion, evaluation, and approval. VCE participants can use a mixture of UNIX and Windows NT platforms.

By using any one of the Deneb simulations in a VCE environment, users increase productivity, speed decision making, reduce costs, and improve time to market. Also, improved communications between engineers, clients, suppliers, and/or product teams prior to product launch reduces the need for multiple revisions and prototypes.

Some current uses for VCE include:
- Interactively evaluate virtual prototypes of designs
- Link remote product teams for Integrated Product and Process Development
- Integrate suppliers, users and clients to gain early design feedback
- Evaluate alternative scenarios
- Conduct daily design/process review sessions
- Train workers at multiple locations
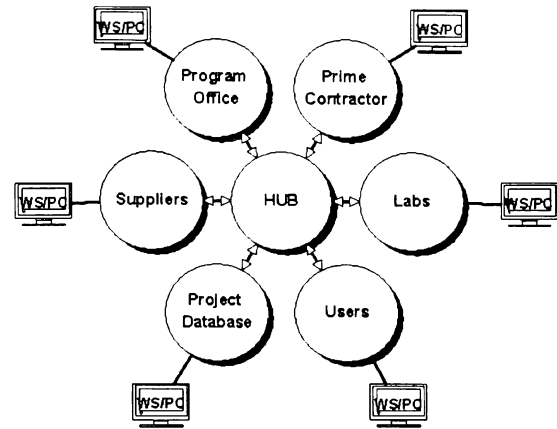- Link integrated product teams early in acquisition programs

Figure 10. Virtual Collaborative Environment

10 VIRTUAL MANUFACTURING BENEFITS

Besides improved communications across multi-disciplinary product teams, specific benefits demonstrated and projected for key industries include:
- 50 percent reduction in time to market based on the increased speed of decision making and the parallel development of product and process designs
- $1-5 billion life cycle cost savings for new Navy/Air Force Aircraft development and production
- Achieve learning curve of third ship set on first ship set for new shipbuilding programs
- Integration of global customers, subcontractors, suppliers and users early in the design and development cycle
- 25 percent reduction in the cost of new products due to the utilization of the Design for Assembly and Design for Manufacturing capabilities
- 70-80 percent reduction in rework costs for tooling and fixtures since they were proven out in the Virtual Manufacturing environment before initial fabrication

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